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SOUND PROPAGATION ELEMENTS IN EVALUATION OF EN ROUTE NOISE OF ADVANCED TURBOFAN AIRCRAFT

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INTRODUCTION

Cruise noise from an advanced turboprop aircraft is reviewed on the basis of available wind tunnel data to estimate the aircraft noise signature at the source. Available analytical models are used to evaluate the sound levels at the ground. The analysis allows reasonable estimates to be made of the community noise levels that might be generated during cruise by such aircraft, provides the basis for preliminary comparisons with available data on noise of existing aircraft during climb and helps to identify the dominant elements of the sound propagation models applicable to this situation.

ATP NOISE CHARACTERISTICS

Experimental data obtained by NASA (Dittmar, NASA-TM-87302) on a scale model eight-blade UDF turboprop configuration were used as the starting point of the analysis. The model consisted of dual eight-blade contra-rotating propellers that were tested at cruise speeds in a wind tunnel. Figure 1 summarizes the noise levels measured at a radius of 0.3 blade diameters for the first six blade harmonics as a function of angle in a horizontal plane relative to the inflow direction. For purposes of this analysis, semi-empirical directivity and spectrum shape models were developed to describe the data. Figure 2 shows the generalized directivity model which indicated that a single directivity curve fit the data quite well for the first five harmonics. The empirical curve also compares reasonably with the theoretical trend expected for the directivity of an eight-blade propeller. Figure 3 shows that a simple model could also be used to define the relative level of each of the harmonics. Also shown are data from Dittmar on an ATP model which show a similar trend in spectrum shape. Based on these empirical models, it was thus possible to estimate the level and directivity at the source of cruise noise from a UDF aircraft. Since the directivity was assumed to be axisymmetric, the model could be used to estimate, to a first approximation, the time history of sound levels on the ground directly under the aircraft or to the side, given a reasonable sound propagation model.

SOUND PROPAGATION MODEL

The basic assumptions made to define the sound propagation model can be summarized as follows:

- At a cruise altitude of 30,000 feet, the acoustic impedance of air is equal to 0.385 times the value at sea level, and this is expected to decrease the sound power radiated by the dipole propeller noise sources by

$$\Delta L_W = 20 \text{ Log } (0.385) = -8.2 \text{ dB}$$

- This decrease in sound power output is partially compensated for by an increase in sound pressure level of one-half this amount. By conservation of energy, for the same sound intensity at 10 km and at the ground, the increase in acoustic impedance at the ground by a factor of 1/0.385 will cause the mean square sound pressure to increase by the same amount, so the sound pressure level will increase by 10 Log (1/0.385) = 4.1 dB. Combined with the above decrease in power level, this results in a net decrease in sound level of 4.1 dB due to the change in acoustic impedance.

- If this change in acoustic impedance happened abruptly, there would be a decrease in sound transmission due to the reflection at an impedance mismatch interface. However, finite difference calculations indicate that there should not be any such transmission loss since the acoustic impedance changes so little over a distance comparable to a wavelength as the sound travels from 10 km to the ground.

- Propagation loss due to atmospheric absorption is estimated according to a forthcoming proposed revision to the American National Standard ANSI S1.26 method for computing atmospheric absorption losses. The currently accepted industry standard method for

computing this loss for aircraft noise, SAE ARP 866A, is not at all usable in its present form for this computation since it does not account for any change in atmospheric pressure nor is it capable of accommodating the extremely wide range of humidity content involved.

- Refraction of the sound emanating from the source is estimated on the basis of simple ray theory assuming a standard linear (lapse rate) temperature gradient of -0.0065 C/meter superimposed on a linear wind speed gradient which was varied from -0.001 1/s to -0.004 1/s.

- Propagation loss due to spherical spreading will be 46 dB between a reference distance of 50 meters from the source and a propagation distance of 10 km.

The predicted cumulative air absorption loss at a (full scale) blade passage fundamental frequency of 250 Hz is shown in Figure 4 as a function of source altitude for a nominal "standard" atmosphere. This uses the 1964 ICOA standard for temperature and pressure and available data on humidity at altitude (USAF Handbook of Geophysics and Space Environments, 1965). Also shown in Figure 4 are predicted values of the air absorption loss based on actual profiles provided by FAA of temperature, pressure and humidity measured at several locations in the U.S. The latter data indicate the "standard" air absorption loss curve in Figure 4 may be conservative. Note also that the greatest rate of increase in the cumulative air absorption loss, which reaches a maximum of 8 to 14 dB at 10 km at 250 Hz, occurs at around 6 to 7 km. The total cumulative air absorption loss for the "standard" atmospheric profile over a 10 km path that was used for Figure 4 is shown in Figure 5 as a function of frequency. Based on pANSI 1.26, the total absorption A(f) to 10 km at frequencies from 50 to 10,000 KHz is very well described by a simple third-order polynomial expression:

$$A(f) = 10^{[3.203 + 3.221X - 0.9552X^2 + 0.14X^3]}, \quad \text{dB}$$

where X = Lg(f) and f is in Hz.

The effect of refraction of the nonuniform atmosphere is illustrated in Figure 6 by calculated sound ray paths for various initial ray angles below the horizontal for a source at an elevation of 10 km on a nominal "standard" day with the temperature gradient identified earlier and a wind speed gradient of -0.002 1/s and for ±50 percent variation in that gradient. The key point here is that only a limited portion of the sound radiated by the source (i.e., ray angles greater than the limiting angle of 35°) would reach the ground, and that small changes in the combined temperature and wind gradient would be expected to cause large variations in the received sound levels on the ground at positions near the point where the "limiting" ray strikes the ground.

It is important to point out, of course, that this simplified sound propagation model makes no attempt to evaluate the fluctuations in sound level that can occur for UDF or ATP noise due to interference effects of multipath transmission and turbulence scattering effects on the blade passage tones in a real atmosphere. However, it should provide a reasonable basis for estimates of the average time history of the noise signature on the ground.

ESTIMATED CRUISE NOISE LEVELS ON THE GROUND

Applying the preceding models, such estimates were made of the time history of sound levels on the ground for the blade passage frequency components of UDF (or ATP) noise. Figure 7 is a typical example of such an estimate for a BPF of 200 Hz. The figure shows the estimated time history for an observer directly under the aircraft flight path and for an observer 10 km and 20 km to the side of the flight track. Note that the sound exposure level, the time integrated measure of noise exposure, drops off very slowly with sideline distance so that the noise carpet created by cruise of UDF/ATP aircraft may be considerably wider than for current turbofan aircraft in cruise or in a climbing mode. Data on the latter are compared in Figure 8 with the estimated range of en route cruise noise levels from UDF/ATP aircraft.

While the estimated levels are, indeed, comparable to those of current aircraft during climb, extrapolation of the latter to levels at en route cruise altitude comparable to that for the UDF/ATP aircraft shows that the noise levels on the ground for the UDF/ATP aircraft would be appreciably higher than en route cruise noise levels of current turbofan aircraft.

SUMMARY

Acoustic measurements of UDF/ATP models in wind tunnel tests can provide a basis for estimating source levels for full size aircraft.

A simplified sound propagation model shows that

- The difference in acoustic impedance between the ground and 10 km is expected to result in a net decrease in sound pressure level of about 4 dB relative to the level for the same source on the ground, ignoring all other effects.
- Cumulative air absorption losses at typical BPF around 200 Hz will amount to about 8 to 14 dB with the greatest losses at 6 to 7 km.
- Refraction effects will limit the sound exposure on the ground to sound rays emanating at angles greater than about 35° below the horizontal.
- Variation in mean temperature and wind profiles may cause large variations in average sideline noise levels.
- En route cruise noise levels of UDF/ATP aircraft will be comparable to those of existing jet aircraft during climb but are likely to exceed appreciably cruise noise levels of existing aircraft.

MEASURED HARMONIC LEVELS FOR MODEL UDF

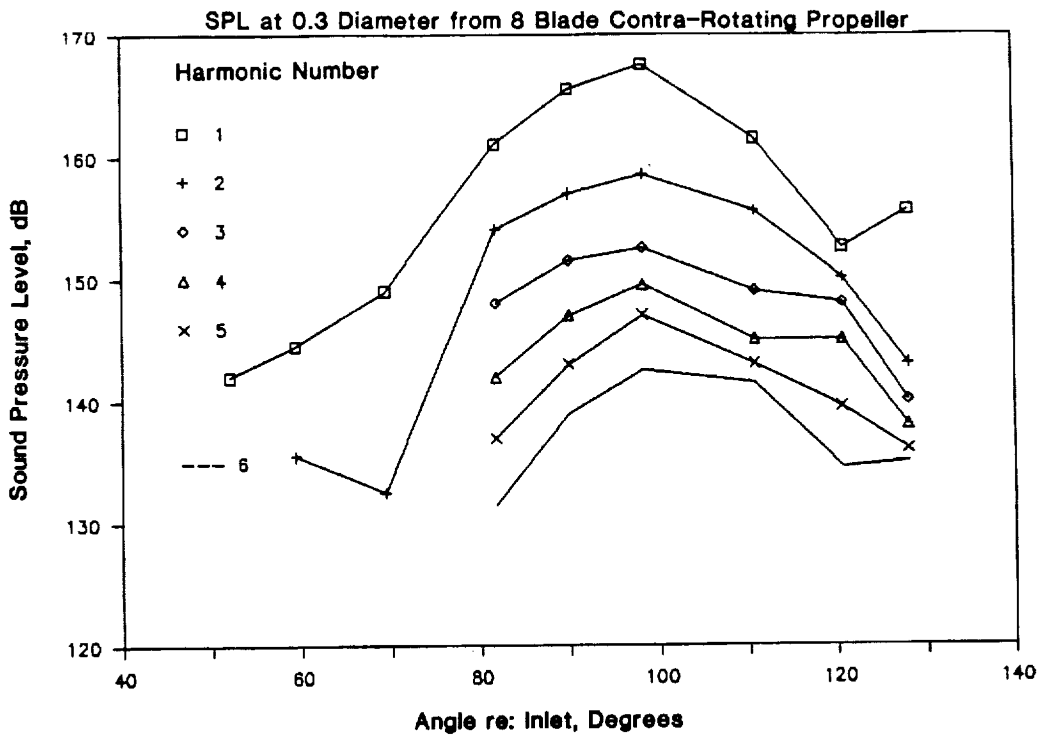

Figure 1.

RELATIVE HARMONIC LEVELS FOR UDF

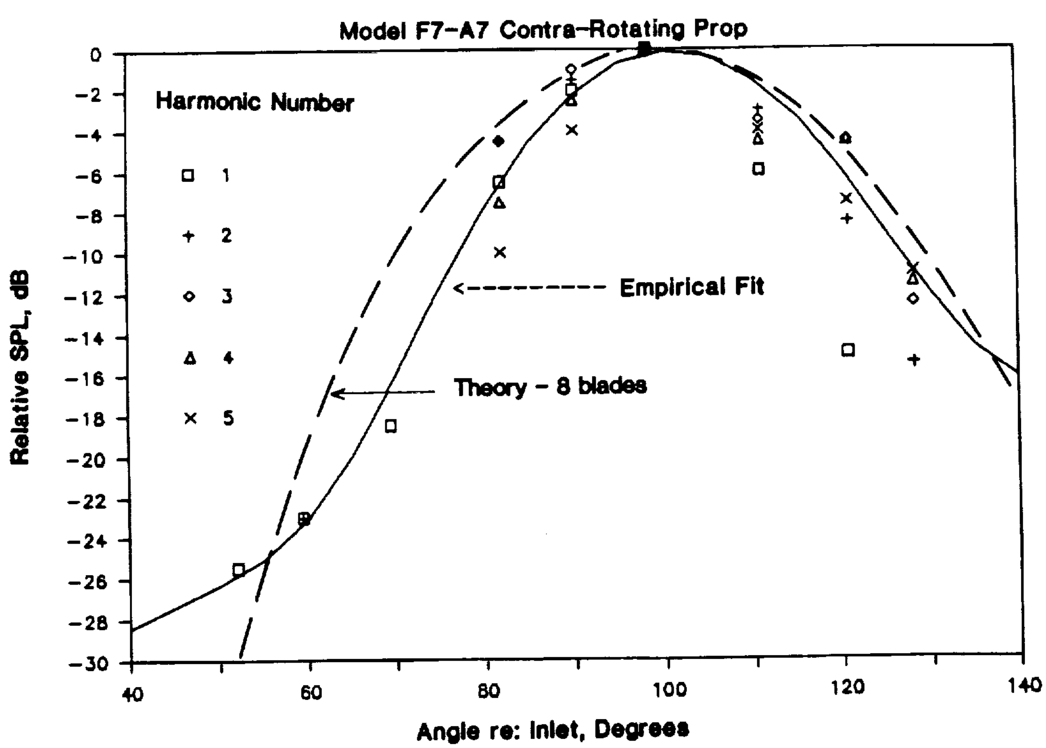

Figure 2.

RELATIVE SPECTRUM FOR 8 BLADE ATP/UDF

DATA FROM DITTMAR, NASA TM 87302

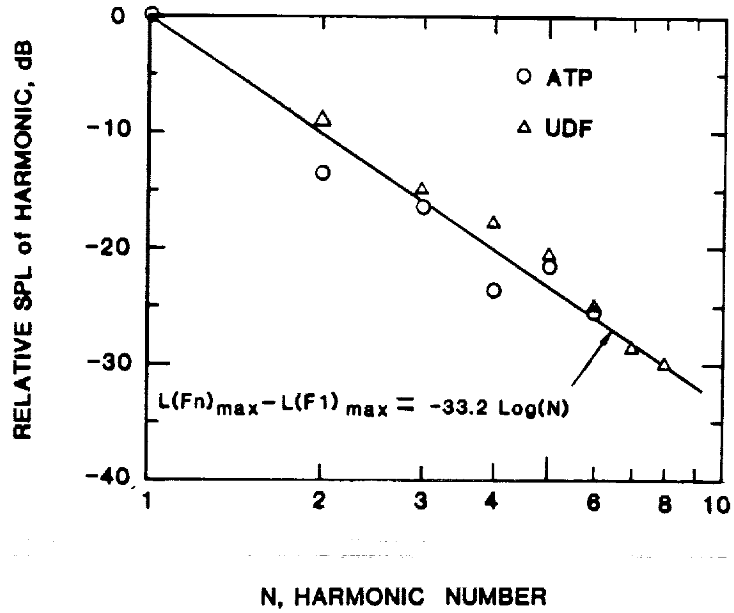

Figure 3.

CUMULATIVE AIR ABSORPTION LOSS at 250 Hz VERSUS SOURCE ALTITUDE

Mean Annual Conditions at 6 Locations Compared to "Standard" Atmosphere in pANSI S1.26

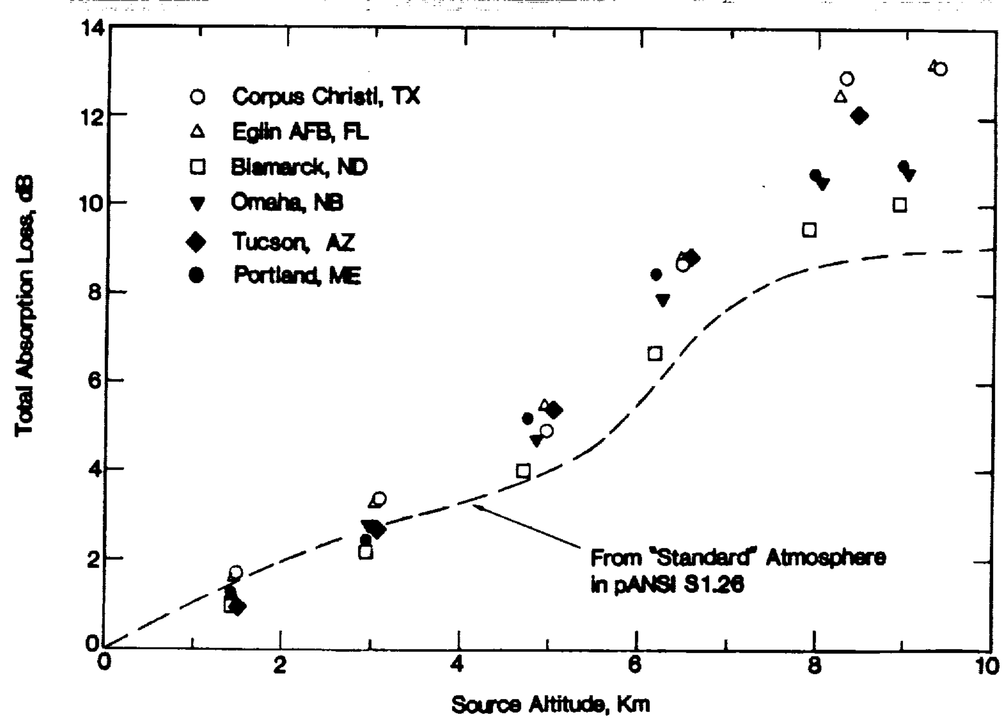

Figure 4.

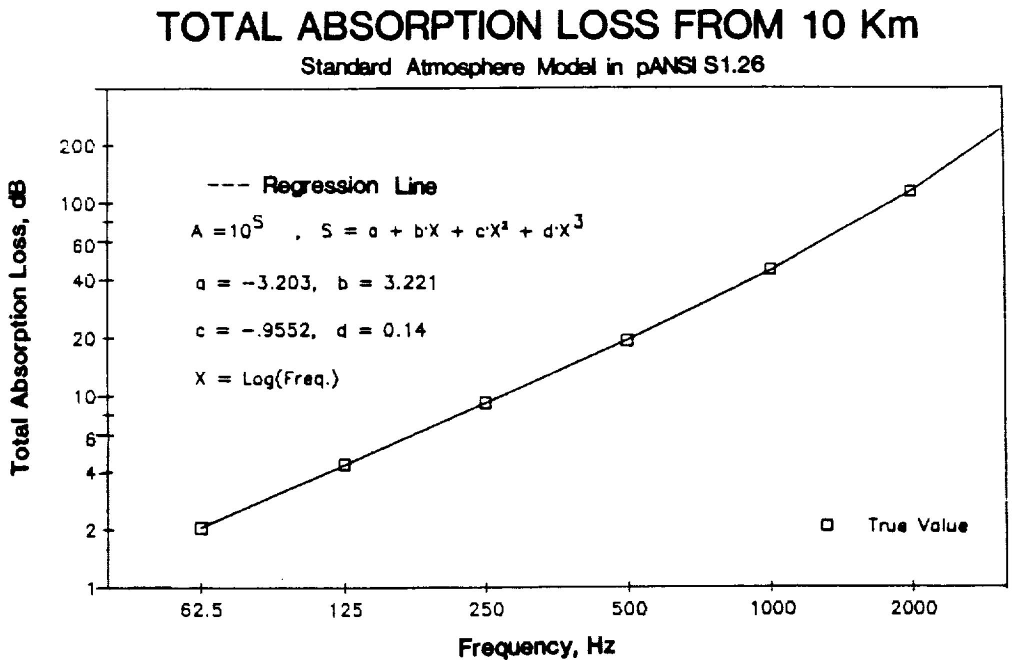

Figure 5.

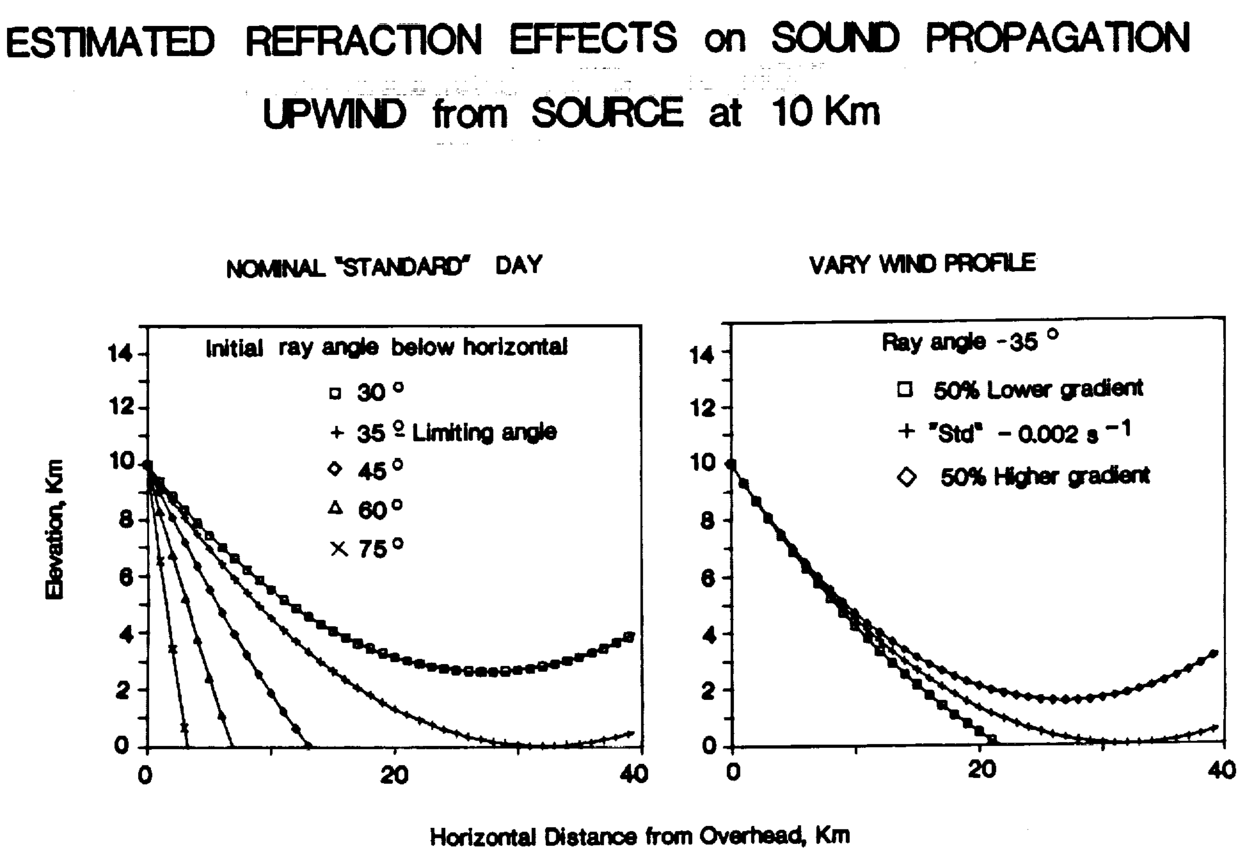

Figure 6.

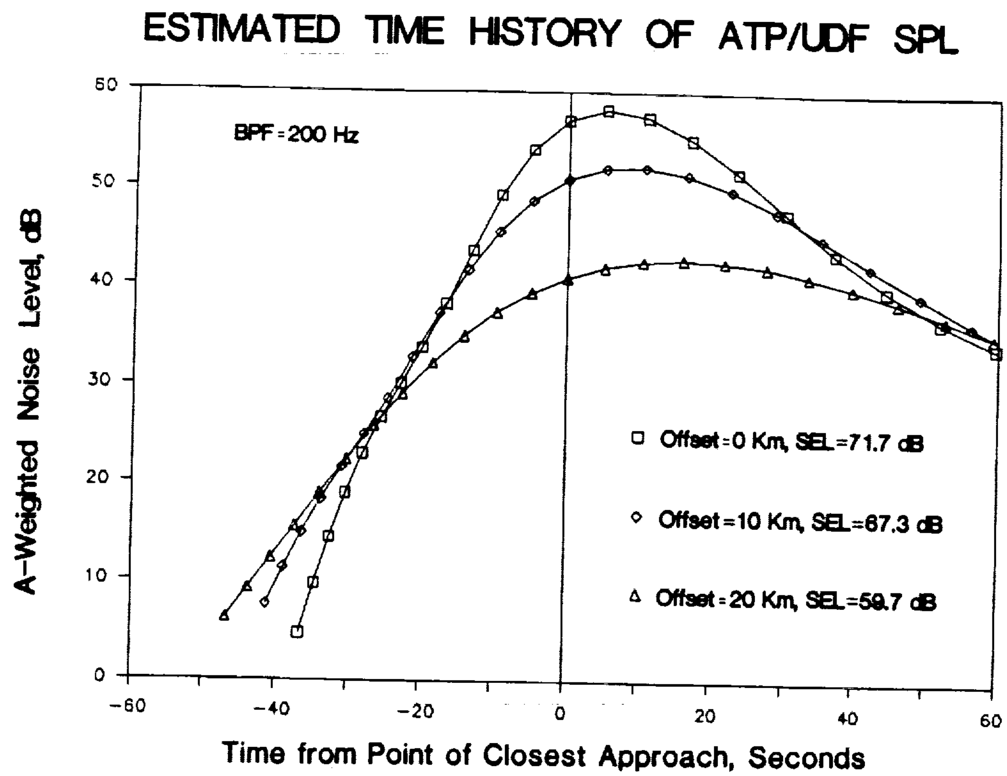

Figure 7.

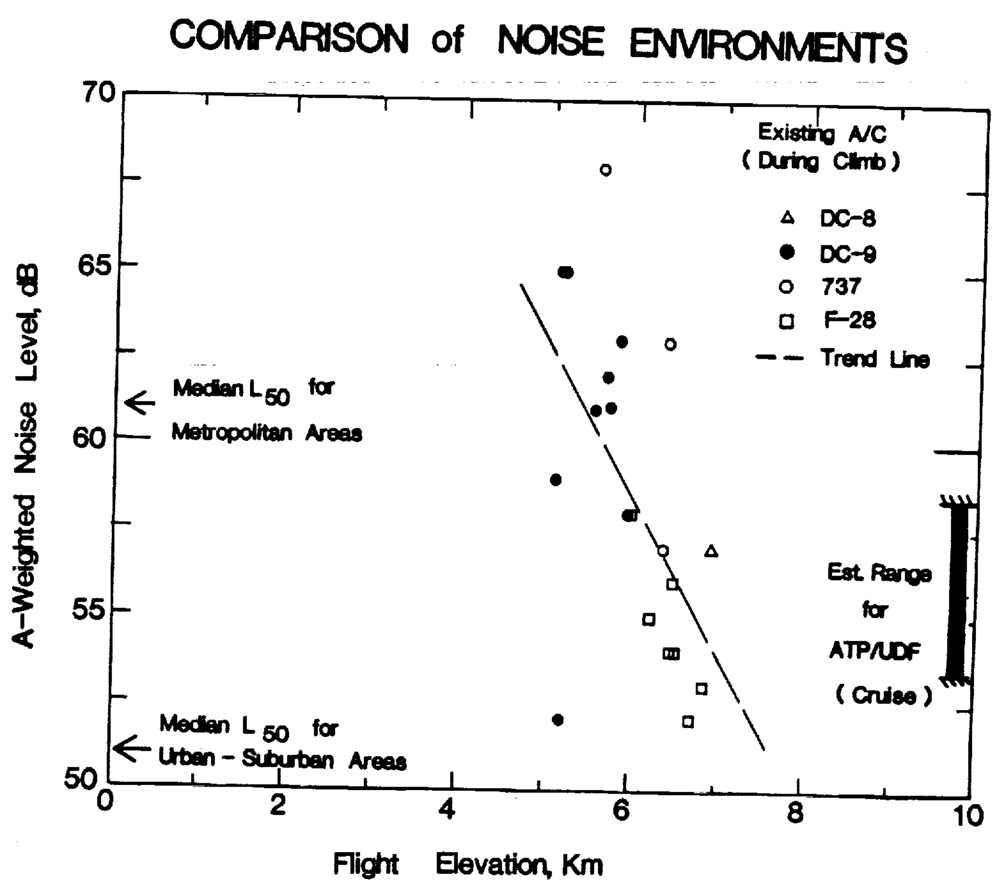

Figure 8.